CALIBRATION OF A NEW TYPE OF PRESSURE GAUGE

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ARMOUR INSTITUTE OF TECHNOLOGY
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The construction and
calibration of a new type

THE CONSTRUCTION AND CALIBRATION
OF
A NEW TYPE OF PRESSURE GAUGE

A THESIS

PRESENTED BY

YOKE H. CHAN

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

MAY 25, 1911

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Introduction.

Pressure gauges that are commonly used in power plants and laboratories are the Bourdon metal tube gauges and the corrugated diaphragm gauges. The accuracy of these are well enough for the ordinary commercial engineering practice; but , where an error of one or two pounds means the acceptance or rejection of a large contract, it is clearly seen that an absolutely accurate pressure gauge is necessary.

The work of thie thesis is the construction and calibration of a new type of pressure gauge. The aim is to study and eliminate the various causes that may effect its true indications . It is the hope of the author that this may be of value and the gauge of such accuracy as to help the solving of the many defects that occur in the other types of pressure gauges.

The History and Construction of Pressure Gauges.

In the early days of engineering the first and simplect form of pressure gauge was the U-tube. It consisted of a U-shaped glass tube partly filled with mercury. Figure "73" shows one of the present

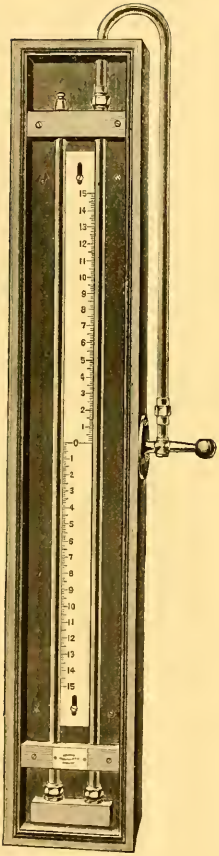

Fig. 73

forms of the U-tube. The pressure from the boiler or other source is admitted to one leg thus lowering the level of the mercury in that leg and raising it in the other leg. The distance between the levels in the two legs determines the pressure. This type of pressure gauge was used exclusively on the low pressure boilers of that time.

As higher pressures came into use, the U-tube pressure gauges were not practicable on account of the necessity of using such high mercury columns. So the engineers of the different countries set to work to devise some means of measuring pressures other than that mentioned above. Vidi, a Frenchman , was the first one to conceive the idea of using a metal box having a vacuum inside. A change in atmospheric pressure causes the metallic box to expand or contract as the case may be. This expansion or contraction of the box is measured by delicate levers, which cause a pointer to travel over a graduated scale.

In 1845. the first Bourdon tube was designed by a German engineer named Herr Schinz, who had one constructed by Roskoff of Coblenz. About four years later Herr Schaffer of Magdeburg improved

on the Vivi idea by corrugating the lid of the elastic metal box. At the same time, a Mr. Smith of Nottingham invented a similar pressure gauge but instead of corrugating the lid he used a membrane of india rubber supported by a spiral spring. In 1850, Bourdon, a Parisian instrument maker, through direct correspondence with Herr Schinz obtained the latter's design of the pressure tube and had it patented. So from that time on the design was known as the Bourdon tube type. Vidi brought suit against Bourdon as to the validity of the patent and won his case, but at that time there was no international patent rights so that the legal decision held good only in his own country. Mr. Dewrance of England, took out patents on the same idea and in 1853 Messrs. Schaffer and Budenburg established themselves in Manchester.

In the mean time steam engines and boilers were increasing in number and soon the three forms of aneroid pressure gauges repla ed the mercurial pressure gauges which had been adopted by James Watt. Few changes have taken place in steam pressure gauges since then, but with the present tendency

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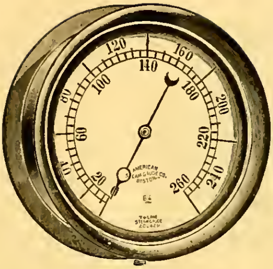

Fig. 4

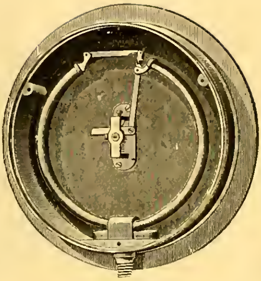

Fig. 5

ORIGINAL LANE GAUGE

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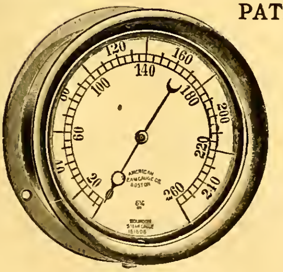


Fig. 1

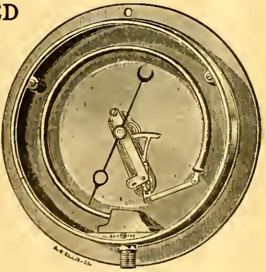


Fig. 3

ORIGINAL BOURDON GAUGES

of using a high degree of superheated steam and a low vacuum has led to improvements which are of interest in connection with this subject.

In 1863 Messrs. Schaffer and Budenburg introduced their steel tube pressure gauges. These tubes are made by boring holes into solid steel rods, truning the outside, flattening and then bending it into shape. The inside of the tubes are then copper lined so as to guard against corrosion. The Manchester Steam User's Association have put them into actual practice and found them to be very accurate, but owing to the complicated troubles which arose in the manufacturing of these tubes and the necessarily high cost they were not used in general by engineers.

It was found that steel being liable to corrode, and brass being semi-plastic, hence much attention was given by the various pressure gauge manufacturers towards discovering a suitable bronze which would not only bend into shape without cracking but would also retain its elasticity when in use.

A great deal may be said of the effect of temperature upon the tubes and also of the imperfect

gearing of the moving parts.

Vibration in a Pressure Gauge.

One of the greatest troubles with pressure gauges is the vibration of their pointers especially when placed on locomotives and ships. The vibration of the pointer is really actuated by the constant oscillation of the Bourdon tube, its connecting rod and the quadrant. Many devices have been tried to counterbalance these different unavoidable motions and Mr. Lane was the first one to conceive the double-tubed system. He attached the quadrant center to the end of one of the tubes and the connecting rod to the other. It was not a great success and consequently not extensively used, for when subject to vibration the quadrant as a whole would jump up and down and at times would disengage itself. Figures "4" and "5" show the original Lane gauge. Mr. Crosby had also invented a similar double-tubed gauge, as did Messrs. Dewrance and Co.; but the latter never developed to any extent.

Some engineers liked to see the pointer vibrate so that their attendant could see that the gauge was in good working order. However, for this mere reason, they could make the front of the gauge

transparent and therefore see the tube vibrate. That is, the boiler attendant could see the tube vibrate violently at right angles to the direction of the connecting rod. There is certainly no reason why all gauges should not be balanced.

On account of the heavy strains in working, transporting shocks, and other disturbing influences, amongst which the rather excessive weight of the pointer is an important item ; the mechanism of pressure gauges has to be of the very best. The workmanship must be of the best if accurate results are to be attained and it must be made of suitable dimensions.

In gauges of this kind there is no theoretical method of determining the amount of motion which the pointer should make for a given pressure. The locations and values of the divisions can only be ascertained by tests in which known pressures are employed.

It is evident, therefore, that pressure gauges, like many other objects, are a compromise, and as perfection in one part leads to troubles in another, so one can only hope for a fairly high standard in either direction.

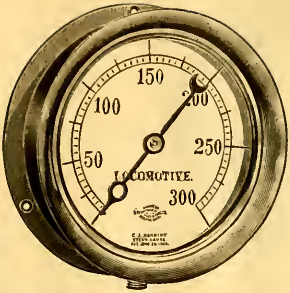


Fig. 15A

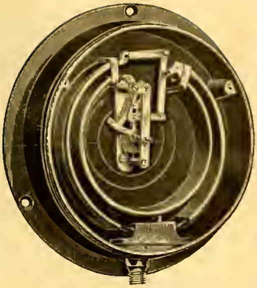
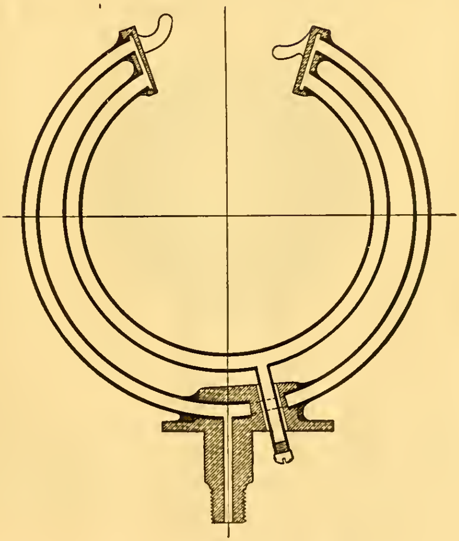


Fig. 15B



SECTIONAL VIEW OF SPRING

The Chief Causes of Errors.

Some of the chief troubles in these gauges are :- 1st, the Bourdon tubes are made of unsuitable material, or badly brazed, or puckered on the inside, and wrongly secured into its socket ; 2nd, the tube the frame, and the gearing, may be made of different materials resulting in serious losses with changes of temperature; and 3rd, the gearing may be punched or badly shaped, the pinions may be rough , their holes slack , and the brackets merely bent into position.

The degree of accuracy that may be expected from a first class gauge is best summed up by the National Physical Laboratory report.

"Inaccuracies of marking may amount to about 1/3 % of the maximum pressure.

The cahnge due to elastic lag, and other changes associated with the elastic properties of metals should be inappreciable. Change of zero due to rise of temperature of 100 degrees Cent. may amount to 1/2 % of the maximum pressure.

Thermal change of elasticity, resulting in indications ehich are higher than the correct pressure may amount to nearly 5 % of the pressure per 100

degrees Cent. increase in temperature.

The vibration of the pointer in unbalanced gauges may have an amount equal to 10 % of the maximum pressure when the vibrations have an amplitude of 1/10 of an inch with 725 revolutions per minute.

Friction may amount to 1/6 % of the maximum pressure. Changes during the entire test may amount to 1 % of the maximum."

The Construction and Calibration of a New Type of Pressure Gauge.

The construction of this type of pressure gauge is much simpler than that of the ordinary Bourdon tube type. The chief advantages are that there are no tubes to bend or no gears to cut, or no pointer to adjust. Figure I represents the actual size of the gauge. It is a form of differential mercury pressure gauge constructed somewhat on the principles of the hydraulic press. Two of these instruments were constructed to measure pressures up to thirty pounds per square inch, and one to measure up to one hundred and twenty five pounds per square inch.

In Plate II a sectional view of the principal parts are shown. B is the base with standard male connections at the bottom. "I" is a brass plunger constructed with the area H smaller than area on the surface of the I. "J" above I is a thin but strong rubber diaphragm held in place by A and B. A is the to part with a three quarter inch outside diameter glass tubing cemented into it. This glass tube has an elliptical inside bore of 1/4 by 1/8 inches, throughout its entire length with its top opening left open to the atmosphere. The gauge is then filled with pure mercury through the top opening "C" until it stands nearly to "0". The size and general appearance of the high and low pressure gauges are the same. The only difference is in the ratio of the areas between H and I.

Before pressure is admitted into H through F, the mercury M in the glass tube stands at 0, the lowest division of the scale "S". Supposing the area of H to be 1/4 part of the area of I, then the unit area of H will be sustained by four units of area I. Consequently, each four pounds of pressure per square inch on H will crate only one pound pressure per square inch on I and the mercury contained in M.

The mercury column in "C" would therefore use only 1/4 as much as it would if directly attached to F.

So it is seen by making I very great in proportion to H, enormous pressure can be measured by a comparatively short column of mercury.

Method of Testing the Low Pressure Gauges.

Plate I shows the general arrangement of the apparatus used in testing the low pressure gauges. The first arrangement consisted only of the parts "F" and a glass tubing cemented to the reducer of the 1/8 inch piping. F Holds a 1/4 by 1/8 inch reducer for the gauge connection, and the lower opening of the T was closed by an iron standard plug. The mercury was poured into the glass tubing from the top a little at a time and each indication was noted. The indications on the gauge were measured by a paper scale divided into tenths of an inch and on the mercury column by a meter stick. Each reading required the climbing up and down on a chair to read the mercury column. This was found to be a most tedious and inaccurate method, and when the mercury column had only reached about 25 inches

the iron plug did not hold as it should have and the mercury shot out in fine particles. The test was discontinued at once and the apparatus was reconstructed and the final arrangement was made as is shown in Plate I. A thin board was made fast to the wall and the mercury column made to lean against this board as shown. On the side of this mercury column a strip of wood was nailed to the board and on it was pasted strips of coordinate paper having marks on it for evey twentieth part of an inch. The top of the horizontal iron pipe was taken as the zero point.

From Plate I, "A" is a bottle having a small spout near the bottom and some rubber tubing was made fast to it. On the other end of this rubber tubing is a small glass tube inserted so as to slide up and down easily inside of the mercury column tubing. The rubber tubing and the small glass tubing are held up by a spring "S" which in turn is held up by the rod B. Rod B can be raised or powered by a set screw. A fine wire which runs behind the board was used to connect the rubber tubing at the lower part of the spring and the lever arm P. The lever arm P is made to travel in the slot

cut in the board. At the bottom of the T a short nipple was connected instead of the plug and at the end a short length of rubber tubing was fastened with a small strong clamp placed near its center. This was done because there was no iron valves made in such small sizes and a brass one cannot be used with mercury. A cylindrical brass tubing with a slot cut in the center and bent back anout 1/4 of an inch on either edge as shown in Plate I was made for a scale to measure the indications of the gauge. The lower part of this brass tubing was made fast to the upper part of the gauge bt means of an adjustable clamp. The scale on this column measured in tenths of an inch.

In starting a run water is put in first until it attains a level with the gauge. This was done to protect the brass plunger and when mercury is let into the glass tube it will trap the column of water between T and the plunger. As water is incompressible it will transmit the pressure from the mercury column to the gauge.

The bottle is then filled to about half full of mercury and the spring is adjusted so as to hold the end of the rubber tubing just a little above

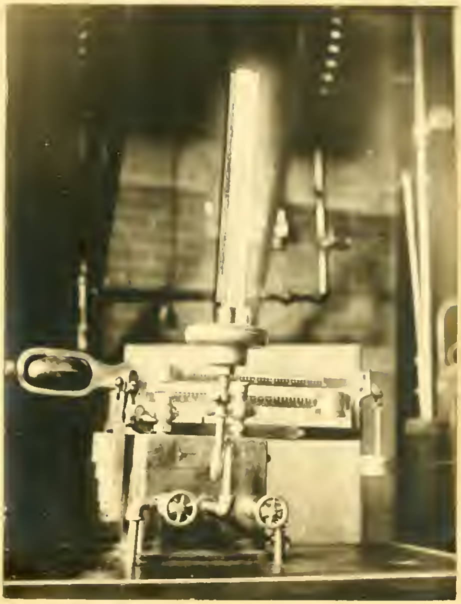


Plate III

the level of the mercury. Now, by a gentle pull on P so that the end of the rubber tubing comes below the mercury level , any amount may be let into the mercury column and read off on the scale H directly without any trouble. So by letting mercury into the column a little at a time and noting the reading of the gauge and of the mercury column after each instance until the mercury has reached the full capacity of the mercury column.

In this manner Gauge #1 and #2 were tested. In Gauge #1 the plunger was a little too tight and a rapping on the side of the gauge was necessary for each reading. Gauge #2 had the same defect but corresponded better to a variation in pressure than Gauge #1. A serries of runs was made both with and without rapping on Gauge #2. A few runs were made with ascending and descending pressure and it was found that the readings did not correspond at all. The gauge always indicated higher than the corresponding height of the mercury when ascending. Thus it shows that there was friction in the plunger.

The high pressure gauge could not be tested here with a mercury column direct as one pound of pressure requires 2.037 inches of mercury, and consequently a mercury column of 254.615 inches is required

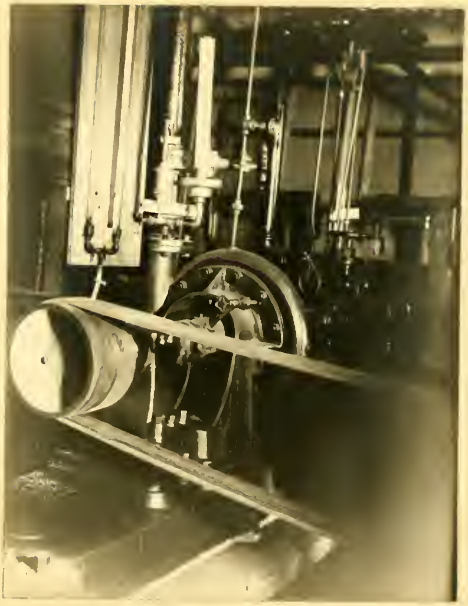


Plate IV

to test the 125 pounds pressure. So it was decided to test it out on the Schaffer and Budenburg steam indicator tester as shown in Plate III.

A series of runs was made and it was noticed that after each separate run the initial mark on the gauge was rising but the higher readings were quite constant. As the steam pressure was only between 75 and 85 pounds the full capacity of the gauge was not tested out.

The low pressure gauge #2 was tested out by connecting it to the exhaust line of the centrifugal pump as shown in Plate IV. The pressure from the pump was connected to a T and with the other openings one was connected to the gauge and the other to the U-tube gauge. Thus the pressure acting on the gauge is the same as that in the U-tube. Much trouble was encountered in making the U-tube mercury tight. The centrifugal pump was driven by a motor and with a speed regulator connected. A carbon rheostat was placed in one of the main lines and a voltmetor was connected across the lines.

A series of runs was made noting the reading on the U-tube and on the pressure gauge with each change of speed. The voltage was kept constant throughout

the entire test by means of the carbon rheostat. The results of this test and of the other tests are recorded and curves plotted, with gauge indications as the ordinates nd the mercury column indications as abcissas.

Conclusion.

From these short and incomplete tests, one cannot arrive at a conclusion as to the exact value of this type of gauge. However, a few pointers have been noted. This type of gauges will not do to indicate boiler pressures or any place where the temperature is high as it will cause a change in the height in the mercury column in the gauge. The principal source of error seems to lie entirely in the plunger and the rubber diaphragm. If the plunger is made so that there is but little friction there is no reason why this type of gauges could not ber made to indicate correctly.

The construction of this type certainly has many advantages over other types and no doubt it could be developed to a higher degree of perfection. It will find its greatest use perhaps

in hydraulic works and compressed air lines, or wherever the temperature is not high. As has been seen, by properly proportioning the area of the plunger the graduations on this type of instrument can be so arranged that any pressure may be measured.

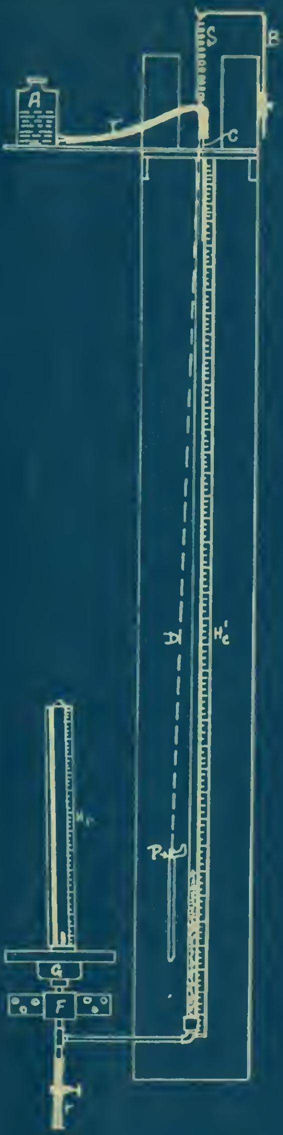


Plate I

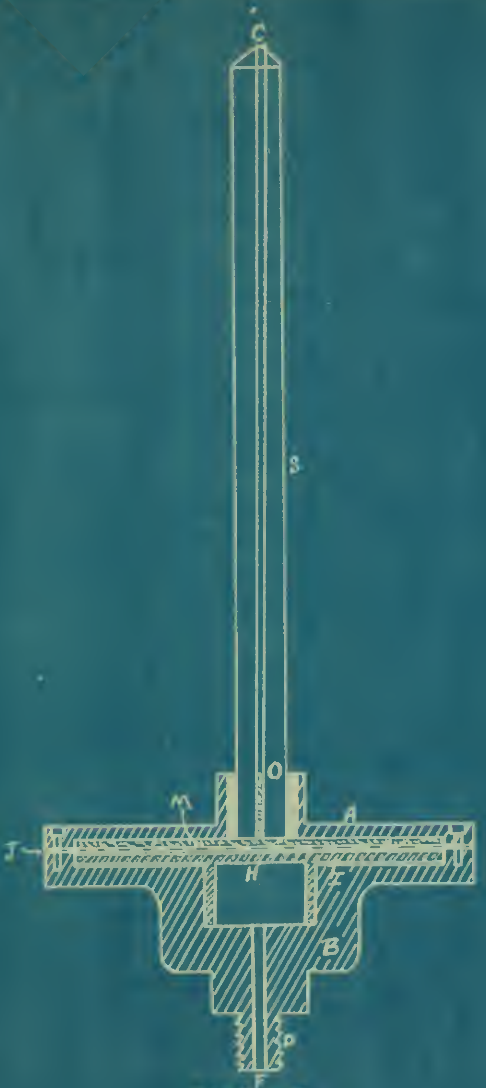


Plate II

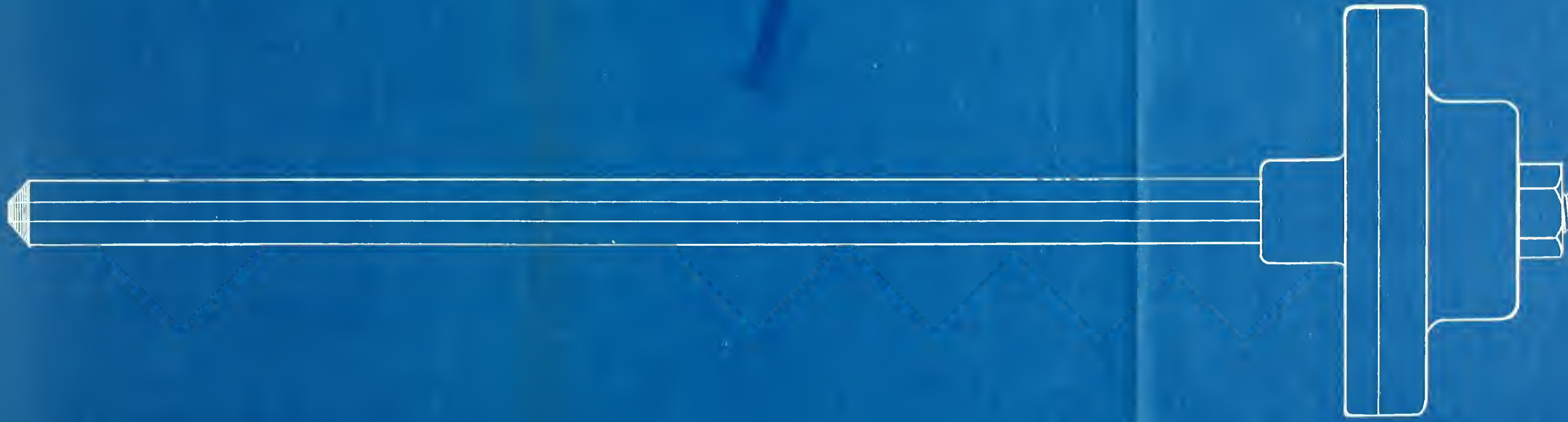


FIGURE 1

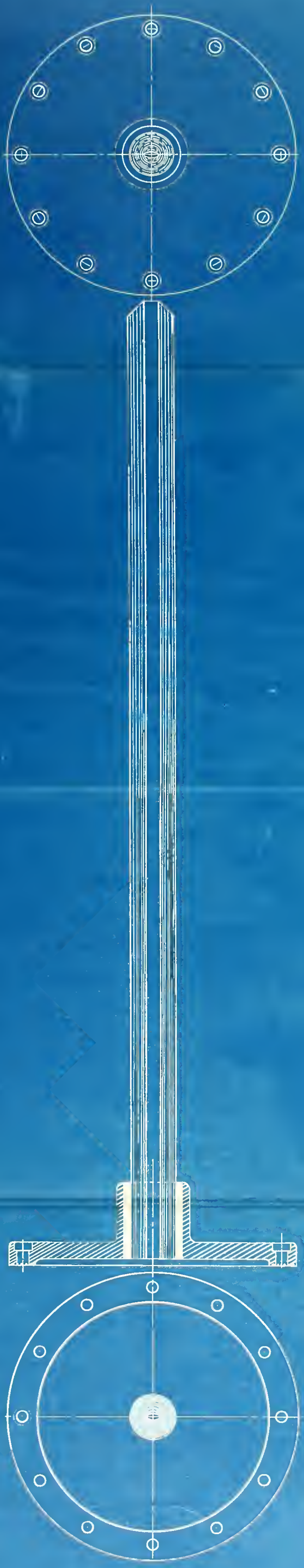


FIGURE II

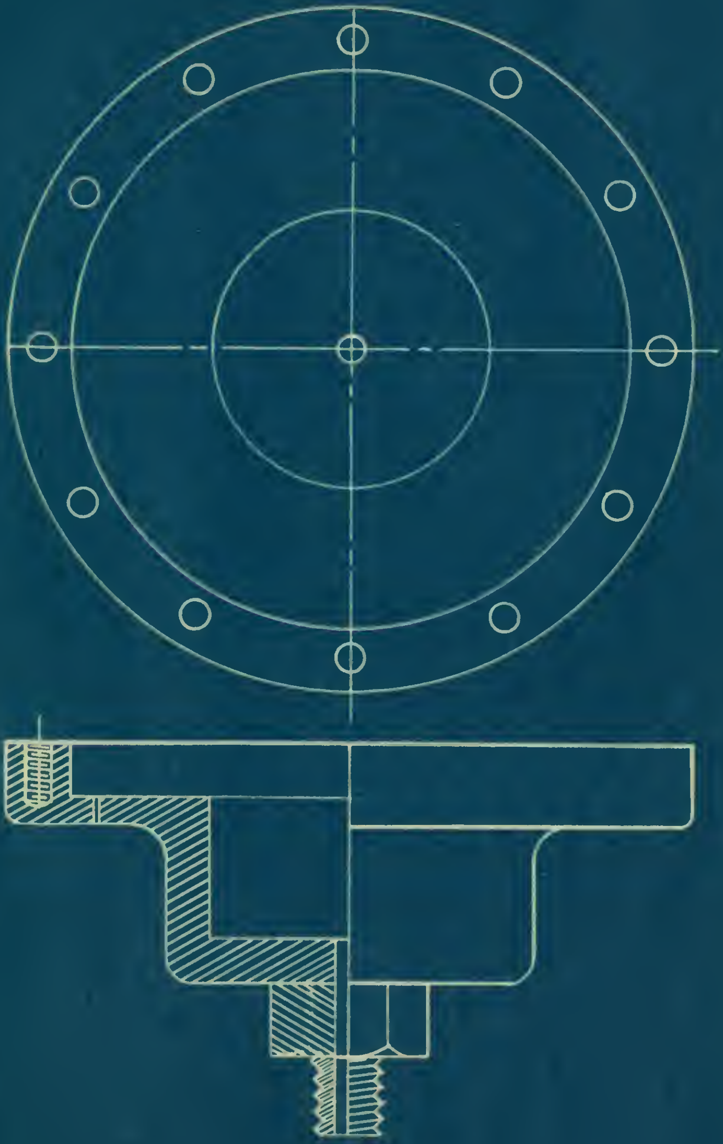


Figure III

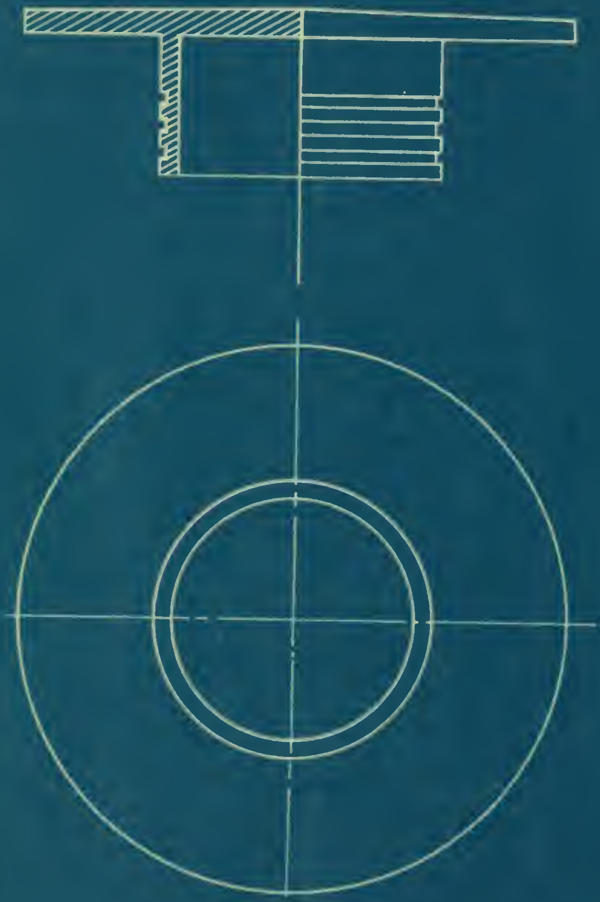
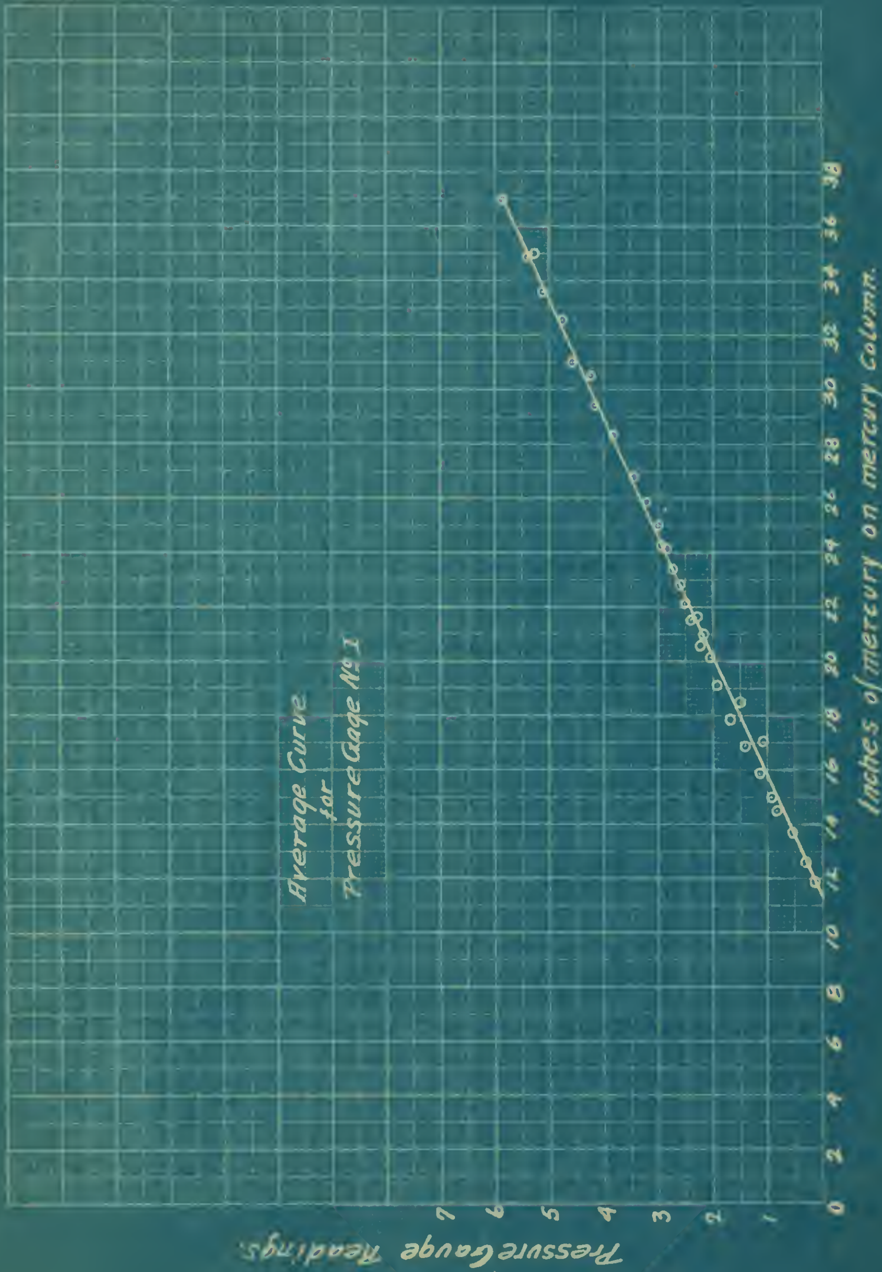
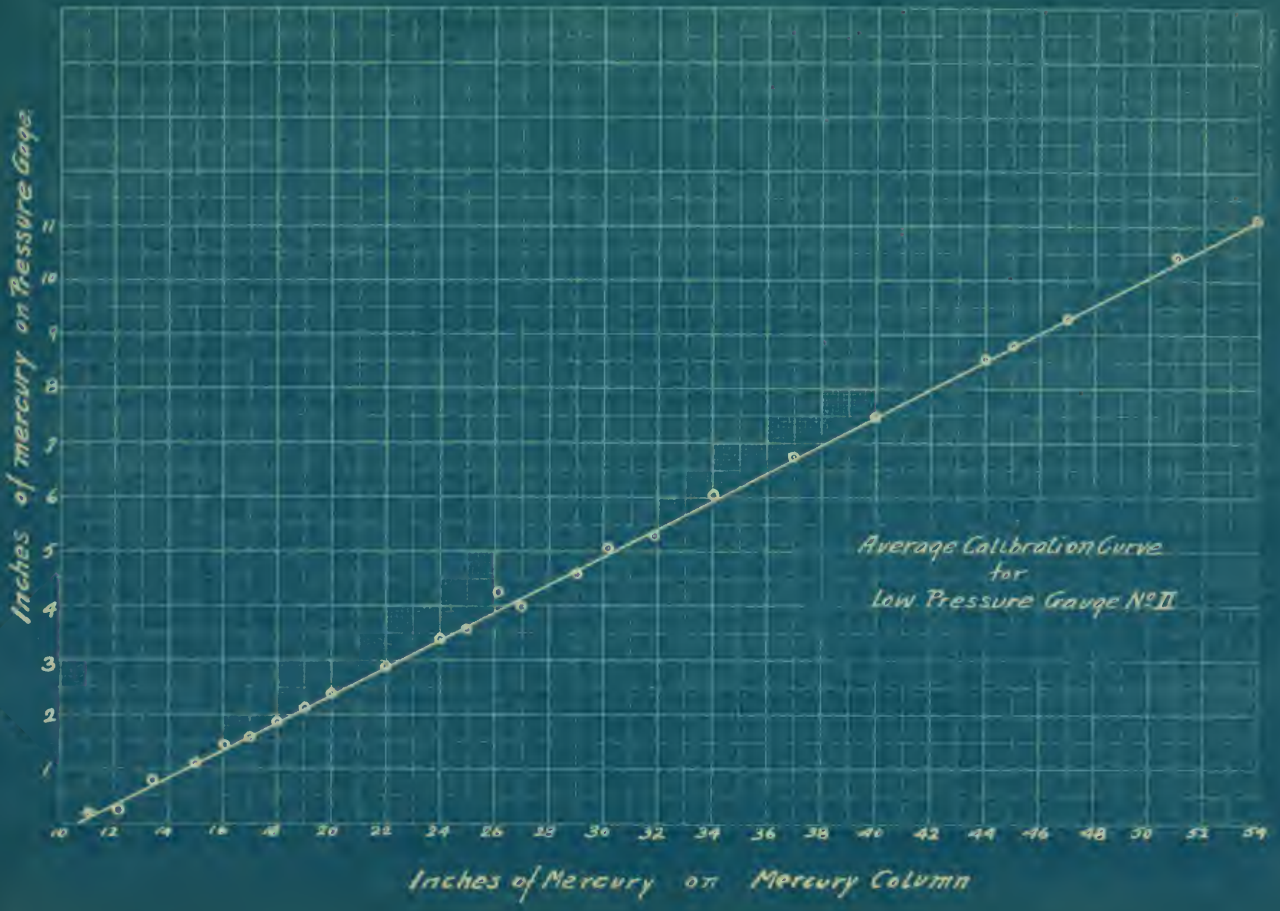


Figure IV


Average Curve
for
Pressure Gage No 1
Inches of mercury on mercury Column
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Pressure Gauge Readings
1
2
3
4
5
6
7



Average Calibration Curve
for
Low Pressure Gauge No. II

Low Pressure Gouge Nº I

H_p = Hight in inches of mercury on Pressure Gouge
H_c = " " " " " " Mercury Column.

A		B		C		D	
H_p	H_c	H_p	H_c	H_p.	H_c	H_p	H_c
1.10	17.00	0.15	11.85	0.10	11.10	0.35	13.05
1.50	18.60	0.30	12.60	0.20	11.60	1.05	15.95
2.05	20.10	0.36	12.95	1.00	15.30	1.70	18.60
2.25	20.85	0.51	13.70	1.40	17.10	2.00	19.70
2.40	21.50	0.82	14.50	2.35	20.95	2.72	23.47
2.55	22.05	0.92	15.00	2.60	22.05	3.35	26.75
2.75	23.35	1.15	15.90	2.98	23.50	4.05	29.65
2.85	24.10	1.42	16.95	3.50	25.85	4.75	32.50
3.00	25.05	1.68	17.80	4.10	28.60	5.35	35.00
3.25	25.90	1.98	19.05	4.25	30.02	5.85	37.00
3.45	26.75	2.20	20.55	4.90	33.20		
3.85	28.25	2.30	21.60	5.85	37.35		
4.18	29.40	2.60	22.95				
4.55	31.00	2.70	23.45				
		2.91	24.25				
		3.20	25.50				
		3.82	28.25				
		4.12	29.20				
		4.22	30.55				
		4.60	31.65				
		5.10	33.60				
		5.40	34.90				

Low Pressure Gauge Nº II

Without Rapping

Hp = Hight in inches of mercury - Pressure Gauge
Hc = " " " " " Mercury Column.

	A		B		C		
	Hp	Hc	Hp	Hc	Hp	Hc	
	0.25	12.20	0.12	11.25	0.20	11.15	
	1.45	16.15	0.28	12.15	0.50	11.85	
	2.29	19.60	0.82	14.00	0.80	13.30	
	2.82	21.60	1.00	14.90	1.00	13.85	
	2.88	22.40	1.34	16.10	1.50	16.90	
	3.18	23.15	1.61	17.20	2.38	20.30	
	3.50	25.00	1.85	18.20	3.30	23.60	
	3.75	26.50	1.99	19.20	3.54	25.00	
	4.00	27.45	2.20	20.25	4.00	26.65	
	4.27	28.15	2.42	21.50	4.61	28.75	
	4.60	29.15	2.55	22.00	5.05	30.35	
	5.20	30.70	2.89	23.05	5.50	32.20	
	5.30	31.90	3.20	24.00	6.02	34.00	
	5.72	33.05	3.72	25.85	6.49	35.75	
	5.98	34.05	4.17	27.15	7.02	38.10	
	6.21	35.06	4.50	28.40	7.51	40.00	
	6.40	36.05	4.78	29.75	8.10	42.05	
	6.85	37.40	5.20	31.00	8.55	43.90	
	7.65	39.90	5.54	32.00	9.30	46.35	
	7.85	41.15	5.75	33.20	9.55	47.60	
	8.65	43.70	5.95	34.12	10.00	49.65	
	8.72	44.40	6.95	37.75	10.67	52.20	
	9.48	46.82	7.62	40.40	11.27	54.90	
	10.00	48.85	8.42	43.20			
	10.49	50.85	9.18	45.95			
			9.52	47.90			
			10.20	50.45			
			10.78	53.15			
			11.80	56.75			

Low Pressure Gauge Nº II

Without Rapping Test for Friction of Plunger				
UP			DOWN.	
Hp	Hc		Hp	Hc
0.20	11.15		11.00	52.21
0.50	11.85		10.50	49.95
0.80	13.30		9.99	47.90
1.00	13.85		9.49	45.90
1.50	16.90		9.00	44.00
2.38	20.30		8.50	41.90
3.30	23.60		7.99	40.05
3.54	25.00		7.50	38.20
4.00	26.55		7.00	36.20
4.61	28.75		6.50	34.40
5.05	30.35		6.00	32.65
5.50	32.25		5.50	30.80
6.02	34.00		5.00	28.80
6.49	35.75		4.50	26.85
7.02	38.10		4.00	24.85
7.51	40.00		3.48	22.75
8.10	42.05		3.00	20.85
8.55	43.90		2.50	19.10
9.30	46.35		2.00	15.65
9.55	47.60		1.50	13.35
10.00	49.55		0.98	11.20
10.67	52.20		0.50	8.90
11.27	54.90		0.00	6.40

Low Pressure Gauge Nº I

With Rapping.				
A			B	
Hp	Hc		Hp	Hc
0.20	11.10		0.05	11.20
0.80	13.40		0.25	11.70
1.18	15.25		0.40	12.60
1.68	17.00		0.75	13.75
2.50	20.40		1.00	14.50
3.05	23.95		1.40	16.00
3.90	26.95		1.70	17.10
5.09	31.30		2.35	19.85
5.65	33.40		2.65	22.00
5.08	35.00		3.05	23.10
6.88	37.95		3.55	24.75
7.60	40.85		4.00	26.25
8.60	44.50		4.38	27.55
9.52	48.05		5.10	30.55
10.02	50.75		5.45	31.75
11.45	56.00		5.70	32.80
			5.82	33.40

HIGH PRESSURE GAUGE

Pressure on Gauge	Pressure on Scale	Pressure on Gauge	Pressure on Gauge	Pressure on Scale	Pressure on Gauge	Pressure on Gauge	Pressure on Scale	Pressure on Gauge
UP		DOWN	UP		DOWN	UP		DOWN
0	0	.15	0	0	.50	.40	0	1.60
0	5	.90	0	5	.60	.45	5	1.70
0	10	1.75	0	10	.80	.50	10	1.80
0	15	—	0	15	—	.70	15	—
.15	20	2.85	.60	20	1.20	.80	20	2.20
—	25	—	1.00	25	—	.95	25	—
1.05	30	4.25	1.60	30	3.10	1.30	30	3.10
1.80	35	—	2.30	35	3.80	1.90	35	—
2.40	40	5.50	2.70	40	4.55	2.40	40	4.50
3.00	45	—	3.00	45	5.00	2.95	45	—
3.60	50	6.70	3.25	50	5.65	3.55	50	—
4.40	55	—	—	55	6.00	4.15	55	—
4.85	60	—	4.50	60	—	4.75	60	5.2
5.30	65	7.60	—	65	—	4.80	65	—
5.75	70	8.00	—	70	6.10	4.90	70	5.2
7.00	75	—	—	75	—	5.00	75	—
7.50	80	8.20	—	80	—	—	80	—
8.10	85	—	6.9	85	—	—	85	—

Low Pressure Gauge N° II on Centrifugal Pump.

VOLTAGE = 111 Volts — Through Entire Test.
H_p = Gage Readings. H_c = U-Gage Readings.

A		B		C		D	
H_p	H_c	H_p	H_c	H_p	H_c	H_p	H_c
.10	4.65	.10	5.80	.10	6.7	.2	4.03
.30	6.40	.20	7.85	1.10	10.7	—	8.40
.85	7.95	.50	10.15	2.65	16.6	.55	8.40
1.40	9.90	1.50	13.30	4.90	24.7	-	—
2.10	12.90	2.35	16.20	7.20	32.8	2.7	16.30
2.90	16.00	3.40	20.00	10.90	45.9	—	—
4.00	20.00	4.60	24.30	11.70	49.8	5.7	27.50
4.95	23.85	5.60	27.20			—	—
5.75	27.20	6.50	30.70			10.6	45.20
6.80	30.55	7.95	35.05			—	—
8.10	35.25	8.90	39.30			11.5	48.60
9.00	39.35	10.50	44.60				
10.30	44.00						
10.40	44.60						